

HIGH VOLTAGE SYSTEM - PLASMA INTERACTION SUMMARY

BY

N. JOHN STEVENS

TRW, INC.

SPACE AND TECHNOLOGY GROUP

SYSTEM INTEGRATION LABORATORY

REDONDO BEACH, CALIFORNIA 90278

ABSTRACT

This paper reviews the possible interactions that could exist between a high voltage system and the space plasma environment. A solar array is used as an example of such a system. The emphasis in this review is on the discrepancies that exist in this technology in both flight and ground experiment data. It has been found that, in ground testing, there are facility effects, cell size effects and area scaling uncertainties. For space applications there are area scaling and discharge concerns for an array as well as the influence of the large space structures on the collection process. There are still considerable uncertainties in the high voltage-space plasma interaction technology even after several years of effort.

INTRODUCTION

A technology investigation of high voltage system interactions with plasma environments was launched about 17 years ago to satisfy a perceived need for such applications as direct drive electric propulsion and advanced communications systems (1-3). This investigation consisted of ground studies and an auxiliary payload spacecraft project called SPHINX, an acronym standing for Space Plasma High-Voltage Interaction Experiment (4). About the same time that this spacecraft was launched and lost (1974), interest in high voltage system interactions decayed.

In the past several years, however, NASA has been conducting mission studies calling for larger satellites to be placed in low earth orbits by the Shuttle (5-8). The culmination of this activity is the proposed Space Station which has a baseline power requirement to the load of 75 KW (9). If a photovoltaic array is used to produce this power, then the array must generate about 200 KW to be able to supply the load, maintain the battery charging, account for line losses and allow for the degradation of the array. The large power numbers used in these studies has stimulated the desire to increase the operating voltages thereby reducing the line current. However, the operation of high voltage systems in space can result in interactions with the space plasma environment that can impact the system performance.

The interactions of concern in high voltage system operations in space can be illustrated using solar arrays as an example. Consider the system shown schematically in Figure 1. This system consists of two large solar array wings surrounding a central body or spacecraft. The solar arrays are assumed to be assembled such that the solar cell covers do not completely shield the metallic interconnects from the environment. These cell interconnects are at various voltages depending upon their location in the array circuits. Hence, the interconnects can act as plasma probes attracting or repelling charged particles. At some location in the array, the generated voltages are equal to the space plasma potential. Since the electrons are more mobile than the ions, the array floats at a voltage that is more negative than positive with respect to the plasma potential. This arrangement gives rise to possible current collection and breakdown phenomena.

The severity of these plasma interactions depends upon the array operational voltage and the plasma environment. The operating voltages are determined from power system requirements while the plasma environment ranges are established by the orbit. Since the operational voltages considered are large enough to affect only the thermal plasma (plasma particle energies less than 2 eV), these interactions are of more concern in the lower altitudes where the density is the highest (see Figure 2).

These interactions have been studied in ground simulation facilities using solar array segments and dielectrics with pinholes as test samples. Tests with pinholes produce repeatable results in the various test facilities. The solar array tests did have discrepancies in the data. Therefore, only the solar array tests will be discussed in this report. The tests were conducted at the Hughes Research Center (10), Boeing Aerospace Company (11), TRW (12), NASA-Lewis Research Center (13-16) and NASA Johnson Space Center (17,18). Two auxiliary payload experiments were also flown (19,20). In the following paragraphs, the results from these studies are discussed with emphasis placed upon the differences arising from the tests. This can be then used to indicate a direction for future programs.

GROUND SIMULATION STUDIES

The majority of tests conducted in this interaction study were done at NASA-Lewis Research Center and at Boeing. This report uses the Lewis data as baseline and will discuss the other data as deviations from this data. This is not intended to suggest that the Lewis data is correct and the other is wrong; it is just a convenient way to explain the interactions and point out discrepancies.

Tests of solar array segments exposed to plasma environments and biased by external power supplies have been conducted for years. The philosophy implicit in such tests is that the interaction measured at each

voltage step in the laboratory can be summed to obtain the performance of a distributed voltage solar array. Hence, it is assumed that there are no interactions between the various parts of the array at different voltages and the phenomena measured should produce worst-case results.

Such plasma interaction tests have been typically conducted in an experimental facility shown schematically in Figure 3. The vacuum chamber is capable of maintaining a background pressure in the 10^{-6} Torr range with the plasma source operating. This source creates the environment by ionizing a gas such as nitrogen, argon or helium. The plasma parameters (number density and particle temperature) are determined by plasma probe measurements. The test sample is mounted in the chamber, electrically isolated, and connected to the bias power supply. A current sensor is placed in the line between the power supply and the sample to measure the plasma coupling current from the sample to ground. A surface voltage probe (such as the one manufactured by TREK) (21) can be used to measure the voltage across the sample during the test. It should be noted that the tank ground is not necessarily the plasma potential. The plasma potential must be determined from the plasma probe readings and corrections to the sample voltage relative to the plasma potential must be made in order to interpret the results of the experiments.

Lewis Research Center Data

Plasma interaction tests have been conducted in various facilities at the NASA-Lewis Research Center since 1969 to support both technology investigation and space flight experiments. It represents the largest body of test data available.

Solar array segments ranging in size from 100 to 13,600 square cm areas were tested in plasma environments ranging from 10^3 to 5×10^4 particles per cm^3 . This data represented a reasonable cross-section of possible panel areas and, at the time, was believed to be adequate for developing area scaling laws.

In order to minimize the number of variables in these studies the collected current was non-dimensionalized and the voltage used was corrected for the plasma potential. The results are shown in Figure 4 A and B for positive and negative bias test data. The current, $I(0)$, is the thermal plasma current to the sample:

$$I(0)_e = 2.7 \times 10^{-12} N_e T_e A \quad \text{for positive bias}$$

and

$$I(0)_i = K N_i T_i A \quad \text{for negative bias}$$

where $K = 9.89 \times 10^{-15}$ for Argon and $K = 1.4 \times 10^{-14}$ for Nitrogen and A is the panel area.

The error bars represent the range of results for a specific voltage, not a variation about a mean.

The major uncertainty in this data is the plasma parameters. The majority of this data lists only an approximate value for density as are values of electron and ion temperatures. The plasma potential is rarely specified. Probe measurements in the chamber indicated that the density was not uniform and before and after tests probe readings indicated that the environment would not be stable during the test. The uncertainty in the plasma parameters during the tests was stated as being uniform within a factor of two. This condition seems to have existed in tests at other facilities that did provide the plasma parameters.

In spite of the variations in the data, it is apparent that the positive bias data shows a transition at +100 volts. This transition has been called "snap-over phenomenon" (22). This data can be empirically fit by using two relationships:

$$\begin{aligned} I &= I(0)_e \times (1.5 \times 10^{-3} \text{ A}) \times (1 + V/T_e) & 0 \leq V \leq 100 \\ I &= I(0)_e \times (A/4) \times (1 + V-100/T_e) & V > 100 \end{aligned}$$

The model predictions are plotted in Figure 4 A. The agreement between the data and predictions is excellent with the exception of the region between 50 and 100 volts where the collection process is undergoing the transition to snap-over conditions.

In negative bias tests, discharges did occur. The threshold for these discharges appeared to be dependent upon the plasma density even though the non-dimensionalization of the data does seem to mask this effect. Below the breakdown threshold the negative bias current data seems to be linearly proportional to the voltage. This relationship can be fit by an expression:

$$I = I(0)_i \times (1.25 \times 10^{-2} \text{ A}) (1 + V/T_i) \quad V < 0$$

The comparison between the predictions and data is shown in Figure 4 B. There is no way to predict, with this model, the transition to a discharge.

Discharge occurrences in the negative bias positions of the array are an important consideration in the use of these systems for space applications. It could be the limiting factor in their operation in space. The original concept for breakdown was that there was a voltage threshold that was plasma density dependent (see Figure 5). Subsequent data analysis at Lewis, however, has indicated that there may be an arc rate phenomenon that must also be considered (23). While there may still be a voltage threshold, arcing can occur at low voltages if held there for long times. The test data was usually taken over relatively short time intervals.

Effect of Facility on Results

Tests have been conducted in facilities other than Lewis Research Center (LeRC). These test results have been reviewed and are summarized here as small segment tests and panel tests.

Small Segment Tests

These tests were conducted in Boeing Aerospace Company facilities under contract to LeRC (11). The tests were conducted in a similar manner to the LeRC tests using nitrogen for the plasma. The principal differences between the two sets of experiments were that the Boeing tests were conducted in an ion pumped chamber and used a Burrowbridge plasma source (24). This plasma source consisted of two large screens separated by a small distance. The ionization was initiated between them and filled the chamber. This type of device generated a plasma with relatively high energy (about 6 to 7 eV electrons and 25 eV ions). The LeRC plasma characteristics were about 1 eV for both electrons and ions.

The principal difference between these tests results is that the Boeing data does not show the snap-over phenomenon in the positive voltage collection (see Figure 6). The electron collection tends to be a uniformly increasing curve with about an order of magnitude larger current at voltages less than 100 volts and about an order of magnitude less at voltages greater than 100 volts. This data can be fit by the following expression:

$$I = I(0)_e \times B \times A (1 + V/T_e) \quad V > 0$$

where (B x A) is the array panel interconnect area.

The negative voltage data obtained in both sets of tests seemed to be in reasonable agreement.

Panel Tests

There have been several tests conducted on high voltage solar array interactions in the 40 foot diameter chamber at Johnson Space Center (JSC) (17). The test that will be discussed here is the one that was conducted jointly by JSC and LeRC personnel to evaluate the effect of facilities on plasma-high voltage interactions (15). The tests at the LeRC were conducted in a 15 foot diameter chamber. The test specimens were a nine panel array (13,6000 cm x 2) and a single panel (1400 cm x 2).

The determination of facility effects can be best shown by comparing the results of the positive bias tests on the smaller, single panel. The data

is shown in Figure 7. Both tests used Argon for the plasma and the densities were within a factor of three. The initial collection characteristics indicated a positive plasma potential in the JSC tests (about 8 to 12 volts) whereas the LeRC tests showed a negative potential (about -5 to -10 volts). The low voltage collection in the JSC tests is about an order of magnitude larger than that obtained in the LeRC tests. Snap-over occurred at about 100 volts in the LeRC tests but at 150 volts in the JSC. The magnitude of the snap-over in the JSC tests was also considerably less than in the LeRC tests. Finally, the positive tests in the JSC facility terminated at about 400 volts with a discharge. Negative bias collection in both facilities produced similar results.

A solar simulation test was run in the JSC chamber using the large nine panel array. The panels were connected in series and illuminated to provide a test on a large array operating open circuit at about 225 Volts in a plasma environment. The voltage of each segment relative to tank ground was measured as was the current flow between the segments. By correcting for the plasma potential, this test indicated that the positive end of the array was at +25 volts while the negative end was at -200 volts. By using the voltage of each panel in sunlight, the voltage distribution in the array was obtained. If the average voltage relative to the plasma potential was used, the average panel current collection should be computed from empirical models developed from the LeRC tests. This, unfortunately, results in predicted electron currents that are an order of magnitude too low while the ions collection predictions seem to be proper.

Therefore, there is still considerable work to be done in understanding the basic plasma collection process in solar arrays.

Discharges

As stated previously all of the data seemed to be in reasonable agreement for negative bias collections. The question of discharges, however, is still not resolved. These threshold variations are indicated in Figure 8. While the onset of discharges is still an unresolved question, a statistical study using arc rates seems to be producing some uniformity in this data (see Figure 9) (23).

SPACE FLIGHT RESULTS

There are really only two sets of space flight data available on this interaction; the Plasma Interaction Experiments 1 and 2 (PIX-1 and PIX-2) data (19, 20). Of the two sets of data, the PIX-2 is the more complete and will be considered here.

The PIX-2 hardware and orbit characteristics have been previously described in the literature and will only be briefly summarized here. PIX-2 was designed to be an auxiliary payload experiment remaining on the second stage of the DELTA launch vehicle and using the DELTA telemetry system after deployment of the payload. The PIX-2 hardware was flown on the IRAS mission on January 25, 1983 and functioned for a total of 19 hours.

The PIX-2 hardware consisted of two parts: the experiment plate and the electrons enclosure. These parts were located 180 degrees apart on the transition area of the DELTA second stage (see Figure 10). The experiments consisted of four solar array segments, about 490 cm^2 each, that could be biased separately or as groups to potentials of up to ± 1000 volts. The bias electronics and measurement circuits were housed in the electronics enclosure.

The positive bias voltage collection tended to follow the laboratory results when the experiment was run in the thermal or wake modes (after correcting for the structure potential). The data showed a snap-over effect at about 100 volts for both single and multiple samples (see Figure 11). The only discrepancy was in fitting the data for the electron collection below 100 volts. Here, the flight data indicated a stronger voltage dependence than the ground data.

In the ram direction, the electron collection was completely different from the ground simulation data. Here, snap-over was suppressed and the current seemed to fit a $3/2$ power of the voltage over the full range of data (see Figure 12).

The negative bias data seemed to show a slope transition at about 100 volts regardless of the velocity mode (see Figure 13). This curve could be fit with empirical expressions that agreed with the laboratory data above 100 volts negative. Below 100 volts negative, the flight data indicated a lower dependence on voltage than the laboratory values.

For discharges under negative bias voltage, the comparison between ground and flight data is shown in Figure 14. Here, discharges are assumed to occur in the flight data when the system shut off completely. The ground data discharge is assumed to occur when there is a deviation from linearity in the current voltage curve. Hence, there is a discrepancy in the definition of breakdown in the two data sets. However, the flight data does indicate a uniformly lower threshold than the ground data. The comparison for the arc rate (23) indicates that the flight arc rate has a stronger voltage dependence than the ground test data (see Figure 15). This has not been answered or explained.

SYSTEM APPLICATIONS

The empirical relationship can be used to predict the behavior of large solar array systems in space even with the differences in the models. For a 300 KW system divided into 8 wings consisting of 32 parallel branches of 26 blocks in series (the Space Station configuration) the floating potential relative to space is shown in Figure 16. It is assumed that the series blocks generate a total 250 volts for operations. It is shown here that the average block voltages are about 5% positive and 95% negative. All of the modifications considered in the previous sections of this report would not change this distribution more than 5%. However, the uncertainty in the technology could be important in the extrapolation of this information to other systems.

Whether or not there would be discharges in this array is also an open question. Arc rate studies indicate that discharges can occur over long mission times. These discharges may be too small to seriously affect the load, but multiple transients on components may still cause failures. The impact of transients on component lifetime has not been adequately evaluated.

If the power supply is connected to the structure, then there is another unknown: the plasma collection of large structure. There are three possible models to be considered for this collection: sphere, plate and thermal. The sphere model assumes a spherical Langmuir probe relationship. The plate model assumes collection based upon Childs-Langmuir sheath sizes (22). The thermal model assumes that the large area collects from the plasma independently of the voltage. As shown in Figure 17, there is considerable difference in the predicted currents resulting from the models. There is a data set from large plate tests in ground simulation facilities at Johnson Space Center (18). This data indicates that large plates would collect more like the thermal model. The tests were conducted using flat metal plates and no information is available for metal/dielectric plates or curved plates.

Applying these models to the prediction of large, high voltage system space performance leads to considerable discrepancies. Using the sphere and plate models, the floating potentials can be changed to be significantly more positive resulting in power losses of up to 10%. Under the thermal or JSC models the power losses are always less than 1%. This discrepancy should be resolved.

One of the engineering responses to the concern for plasma effects in high voltage space systems is to recommend the use of an AC transmission line to carry power from the generator to the load. This would make the space system comparable to the ground power generating systems. Unfortunately, even less is known about AC effects in plasmas than DC. It is known that the desired frequencies are close to the ion resonance frequencies of the plasma (20 KHz). The effects of the Earth's magnetic

field and AC breakdown processes in this plasma are unknown and must be evaluated.

CONCLUDING REMARKS

The concept of high voltage systems for space applications has been evaluated over the past 17 years in both ground simulators and auxiliary payload flight experiments. There are considerable gaps in understanding this technology. The models for plasma collection of both electrons and ions are uncertain when nonuniform structures are considered. The possibility of discharges exist and the effect of discharge transients on system component lifetimes are unknown.

Applying this uncertain technology to system performance computations is also risky. The behavior of a power system coupled to a large structure can not be predicted with any surety. The effect can either be somewhere between none and 10% loss in power. The possible engineering solutions considered to date only have the comfort of having insufficient information to show that they would have a detrimental effect.

REFERENCES

1. Cole, R. W., Ogawa, H. S. and Sellen, J. M., Jr.; "Operation of Solar Cell Arrays in Dilute Streaming Plasmas", NASA CR-72376, March 1968.
2. Knauer, W., Bayless, Jr. R., Todd, G. T. and Ward, J. W.; "High Voltage Solar Array Study", NASA CR-7275, May, 1970.
3. Springgate, W. F.; "High Voltage Solar Array Study", NASA CR-72674, May, 1970.
4. Stevens, N. J.; "Solar Array Experiments on the SPHINX Satellite", NASA TMX-71458, 1973.
5. "Outlook for Space", NASA SP-386, 1976.
6. Johnson, R. D. and Howlbrow, C., eds.; "Space Settlements, A Design Study", NASA SP-413, 1977.
7. Bekey, I.; "Big Comsats for Big Jobs at Low User Costs", Astronautics and Aeronautics, Vol 17, February 1979, pp. 42-56.
8. Snoddy, W. C.; "Space Platforms for Science and Applications", Astronautics and Aeronautics, Vol 19, April 1981, pp 28-36.
9. NASA Space Power Workshop, NASA Lewis Research Center, April 20-22, 1984, NASA CP-2352, 1984.
10. Herron, B. G., Bayless, J. R. and Worden, J. D., "High Voltage Solar Array Technology", AIAA Paper No. 72-443, April 1972.
11. Kennerud, K. L., "High Voltage Solar Array Experiments", NASA CR-12180, March 1974.
12. Inouye, G. T. and Sellen, J. M. Jr.; "TDRSS Solar Array Arc Discharge Tests", Spacecraft Charging Technology-1978", NASA CP-2071/ AFGL TR-79-0082, 1979, pp. 834-853.

13. Domitz, S. and Grier, N. T.; "The Interaction of Spacecraft High Voltage Power Systems with the Space Plasma Environment", Power Electronics Specialists Conference, IEEE, NJ, 1974, pp 62-69.
14. Stevens, N. J., Berkopce, F. D., Purvis, C. K., Grier, N. T. and Staskus, J. V.; "Investigation of High Voltage Spacecraft System Interactions with Plasma Environments", AIAA Paper No. 78-672, April 1978.
15. Grier, N. T.; "Experimental Results on Plasma Interactions with Large Surfaces at High Voltages", NASA TM-81423, January 1980.
16. Stevens, N. J.; "Review of Biased Solar Array-Plasma Interaction Studies", NASA TM-82693, April 1981.
17. McCoy, J. E. and Konradi, A.; "Sheath Effects Observed On a 10-meter High Voltage Panel in Simulated Low Earth Orbit Plasmas", Spacecraft Charging Technology-1978, NASA CP-2071/AFGL-TR-79-0082, 1979, pp 315-340.
18. Konradi, A., McIntyre, B. and Potter, A. E.; "Experimental Studies of Scaling Laws for Plasma Collection At High Voltages", Journal of Spacecraft and Rockets, Vol 21, No 3, May-June 1984, pp 287-292.
19. Grier, N. T. and Stevens, N. J.; "Plasma Interaction Experiment (PIX) Satellite Results", Spacecraft Charging Technology-1978, NASA CP-2071/AFGL TR-79-0082, 1979, pp 295-314.
20. Purvis, C. K.; "The PIX-2 Experiment: An Overview", Spacecraft Environmental Interactions Technology-1983, NASA CP-2359/AFGL TR-85-0018, 1985, pp. 321-332.
21. Berkopce, F. D., Stevens, N. J. and Sturman, J. C.; "The Lewis Research Center Geomagnetic Substorm Simulation Facility", Proceedings of the Spacecraft Charging Technology Conference, C. P. Pike and R. R. Lovell, eds., AFGL TR-77-0051/NASA TMX-73537, February 1977, pp 423-430.
22. Purvis, C. K. Stevens, N. J. and Berkopce, F. D.; "Interaction of Large, High Power Systems with Operational Orbit Charged-Particle Environments", NASA TMX-73867, 1977.
23. Ferguson, D. C.; "The Voltage Threshold for Arcing for Solar Cells in LEO - Flight and Ground Test Results", NASA TM-87259, March 1986.
24. Burrowbridge, D. R.; "A Technique for Simulating the Ionospheric Plasma", NASA Report X-325-68-172, May 1968.

ORIGINAL PAGE IS
OF POOR QUALITY

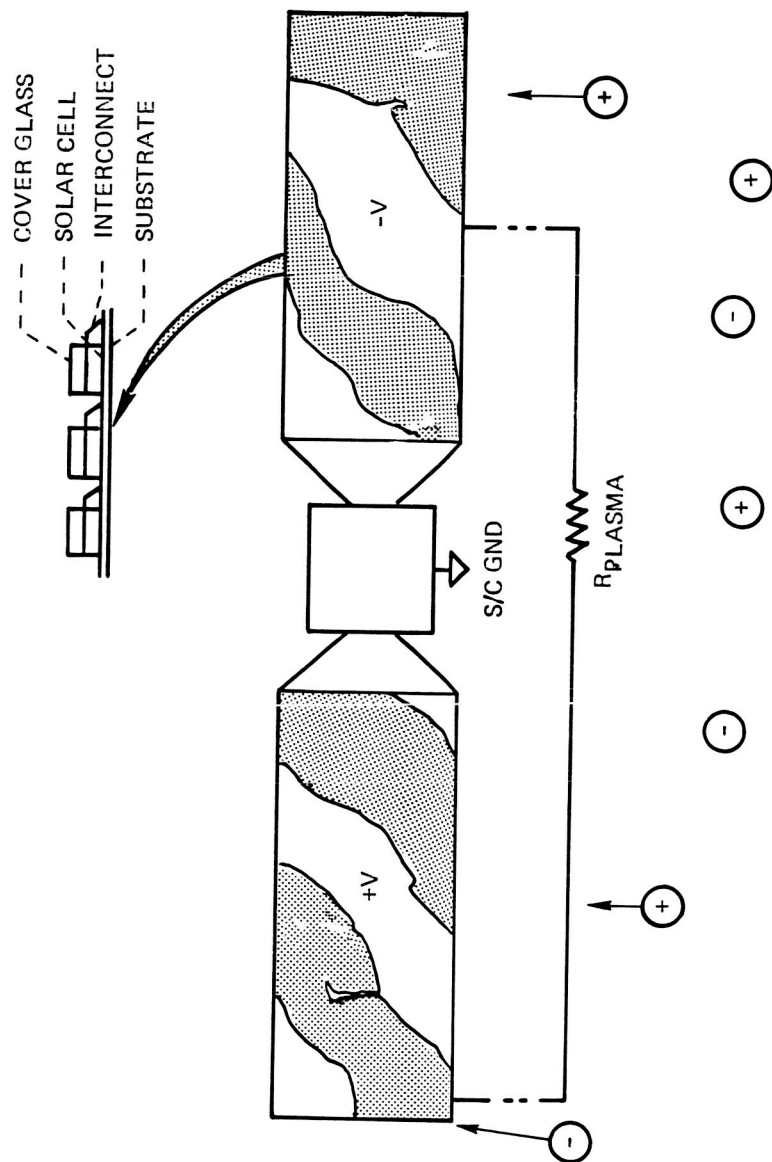


Fig. 1. Spacecraft High Voltage System-Environment Interactions

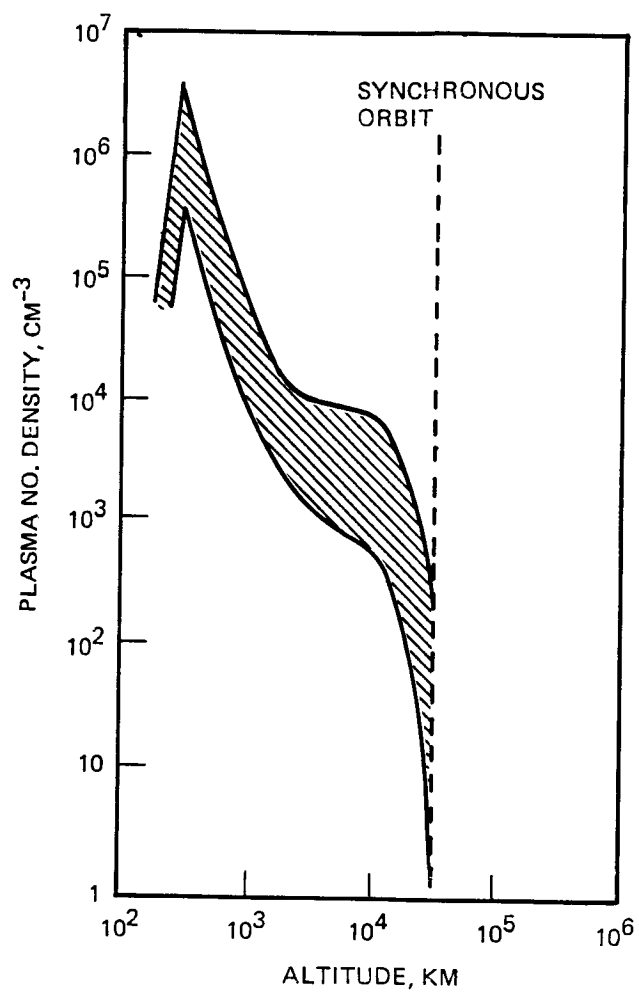


Fig. 2. Plasma Density as Function of Altitude Equatorial Orbit

c-3

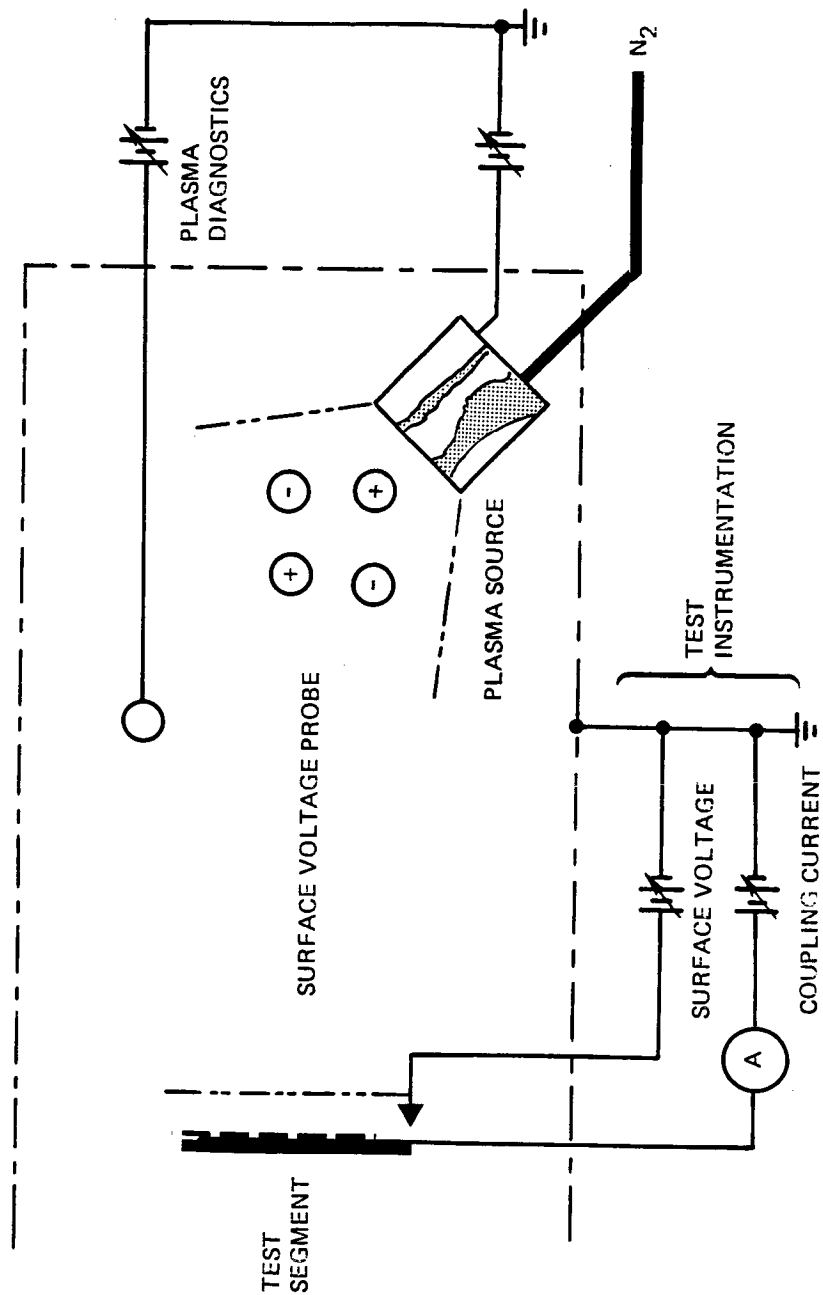


Fig. 3. Schematic Diagram of Test Management

A. Positive Bias Voltages

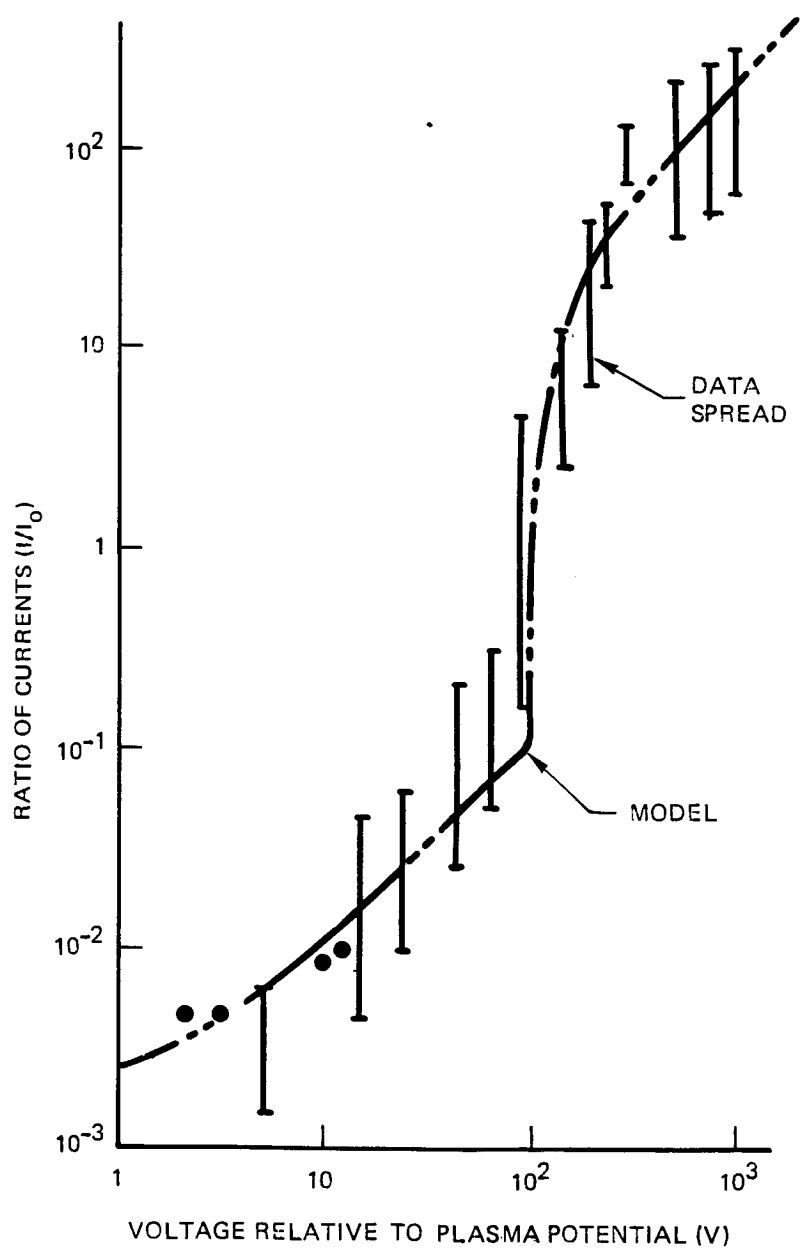


Fig. 4. Summary of Ground Test Data — LeRC

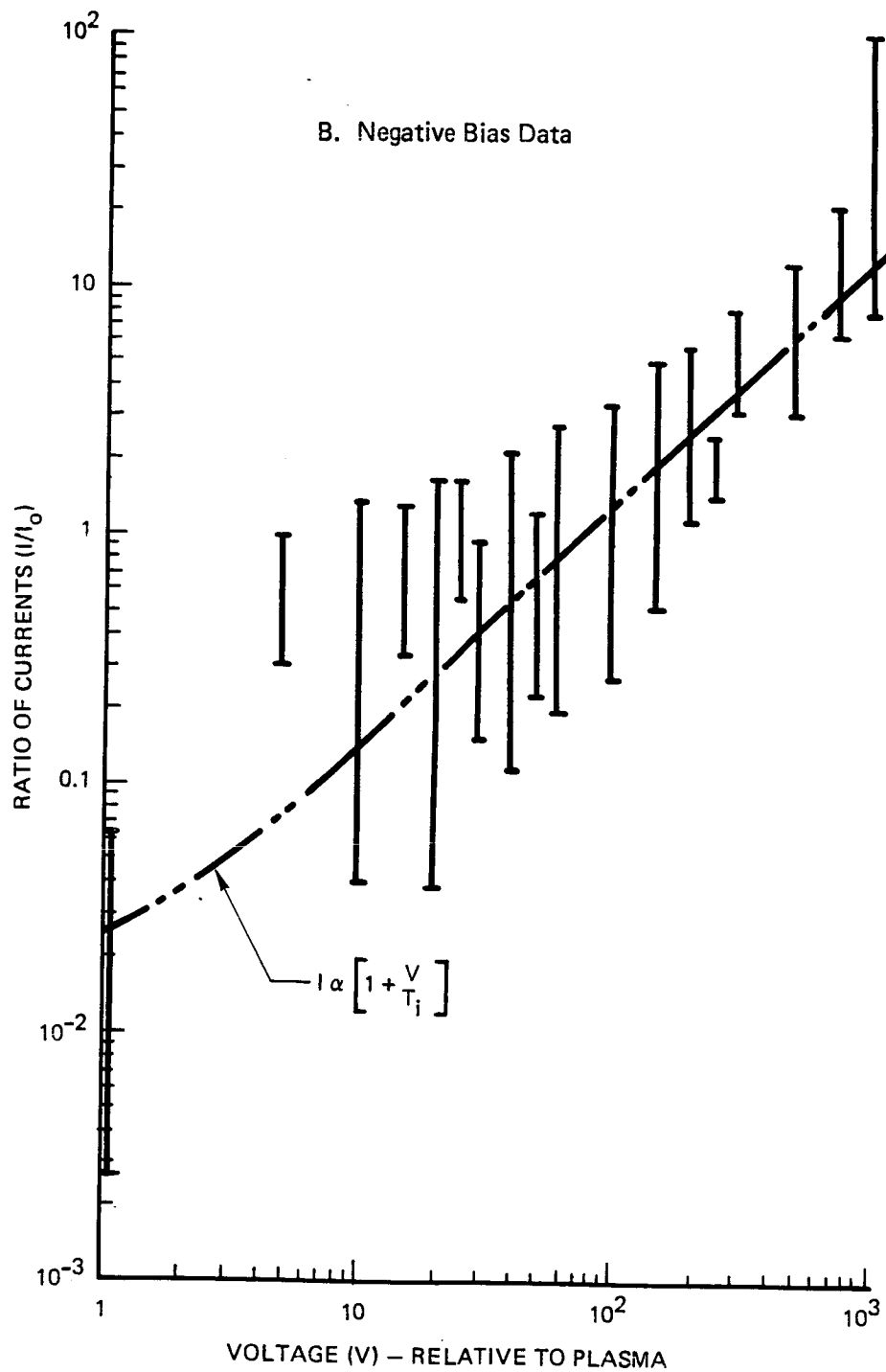


Fig. 4. Summary of Ground Test Data – LeRC

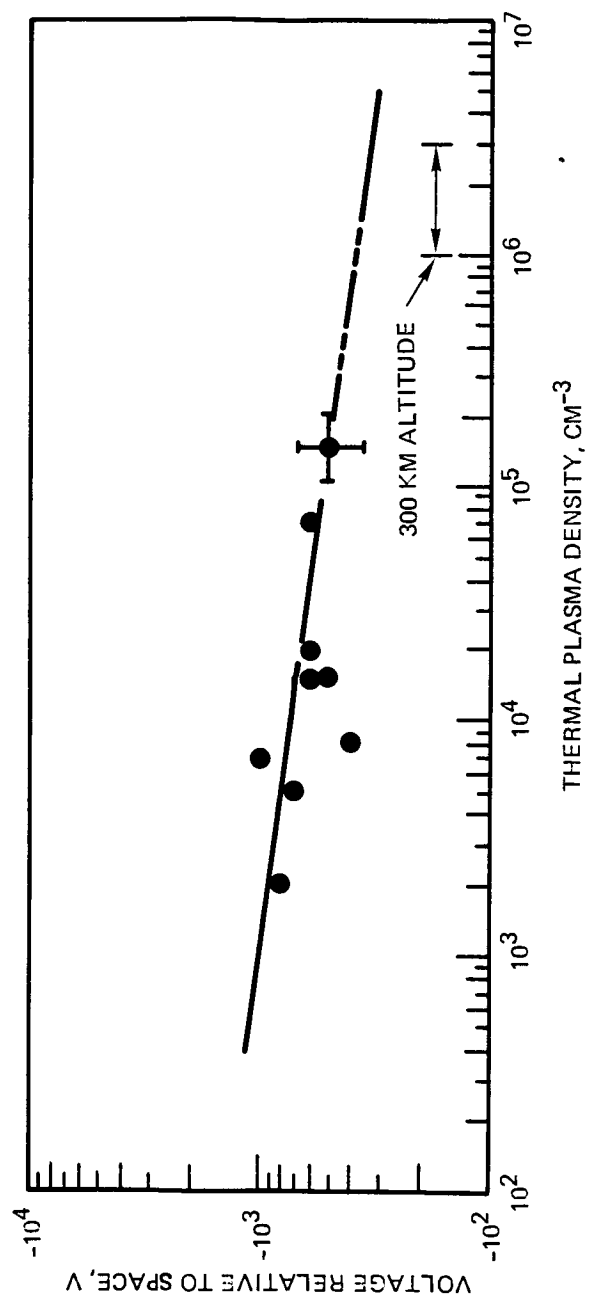


Fig. 5. Voltage Threshold for Breakdown

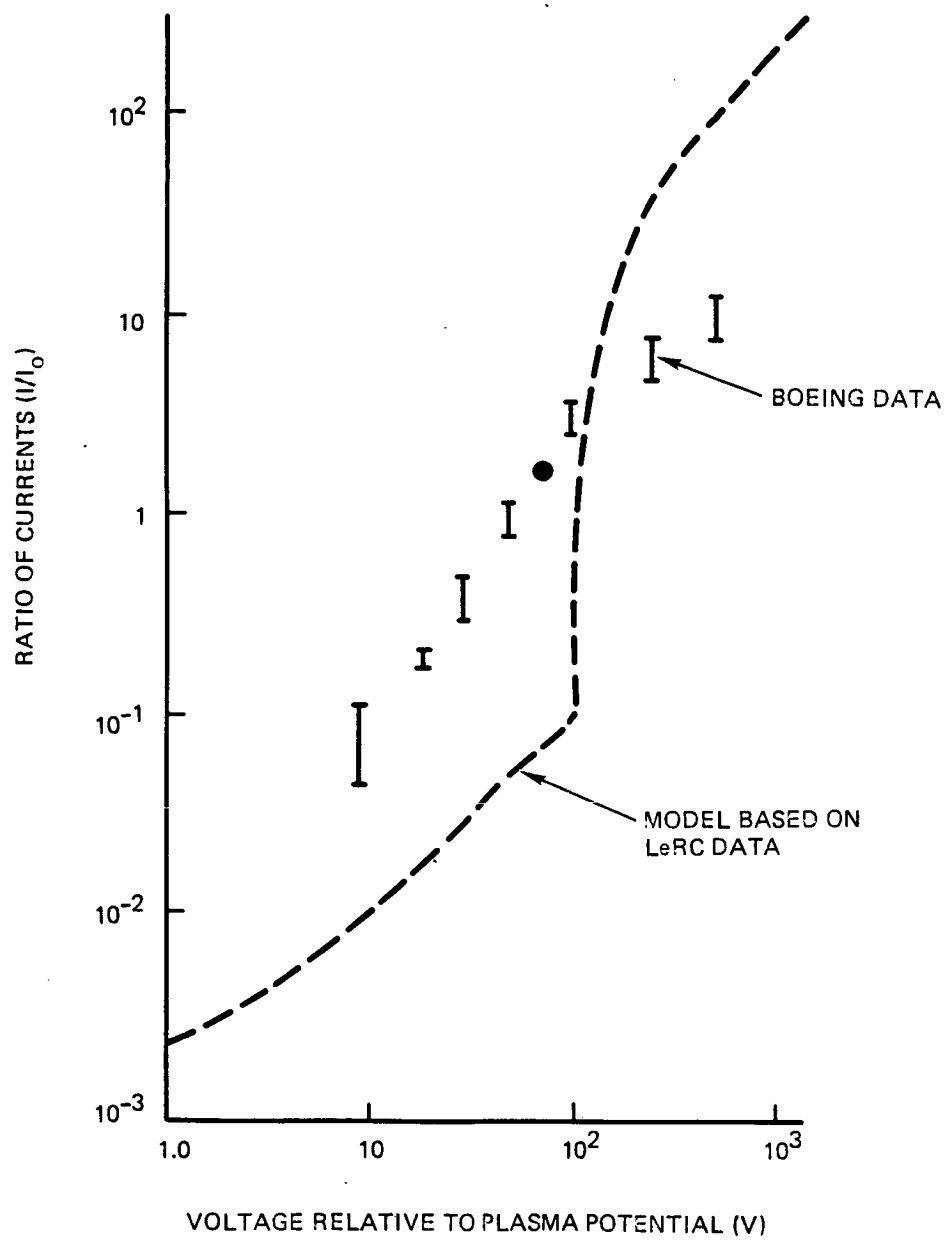


Fig. 6. Comparison of Ground Test Results

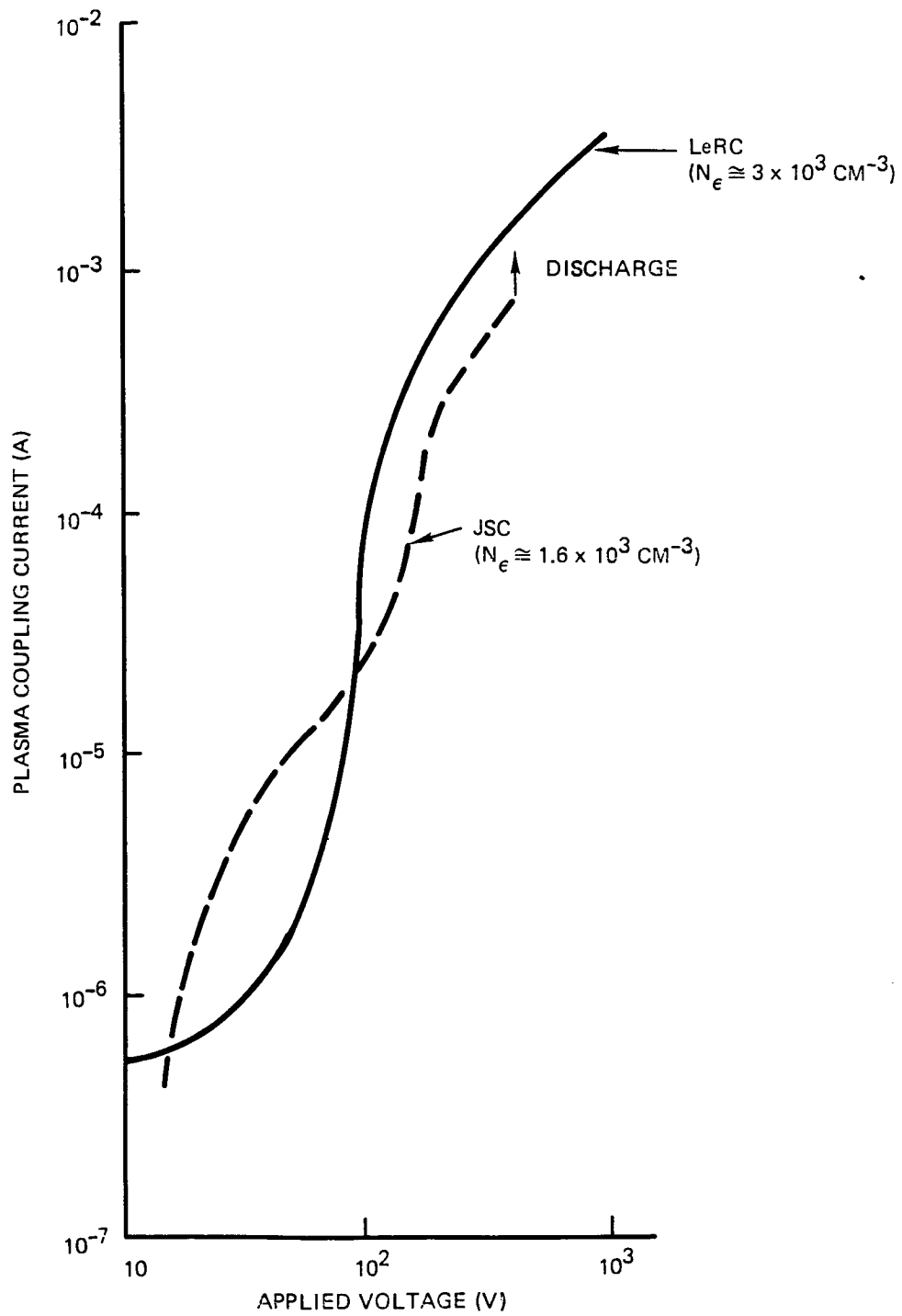


Fig. 7. Comparison of Tests in Different Facilities
1400 cm² Solar Array Panel

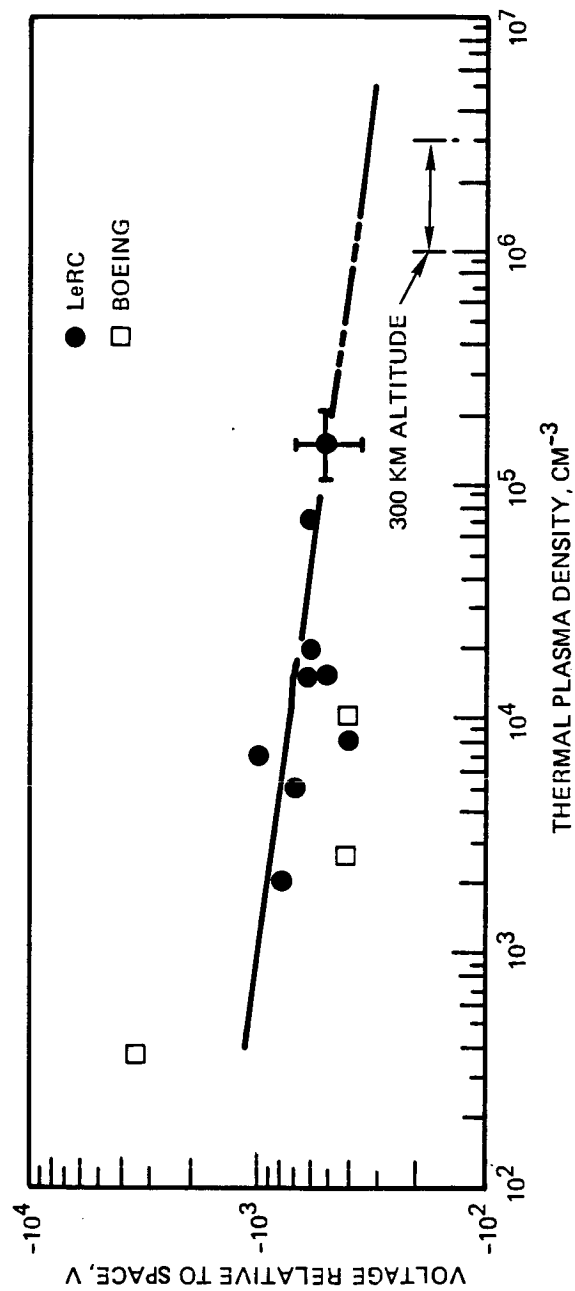


Fig. 8. Voltage Threshold for Breakdown

LeRC and Boeing Data

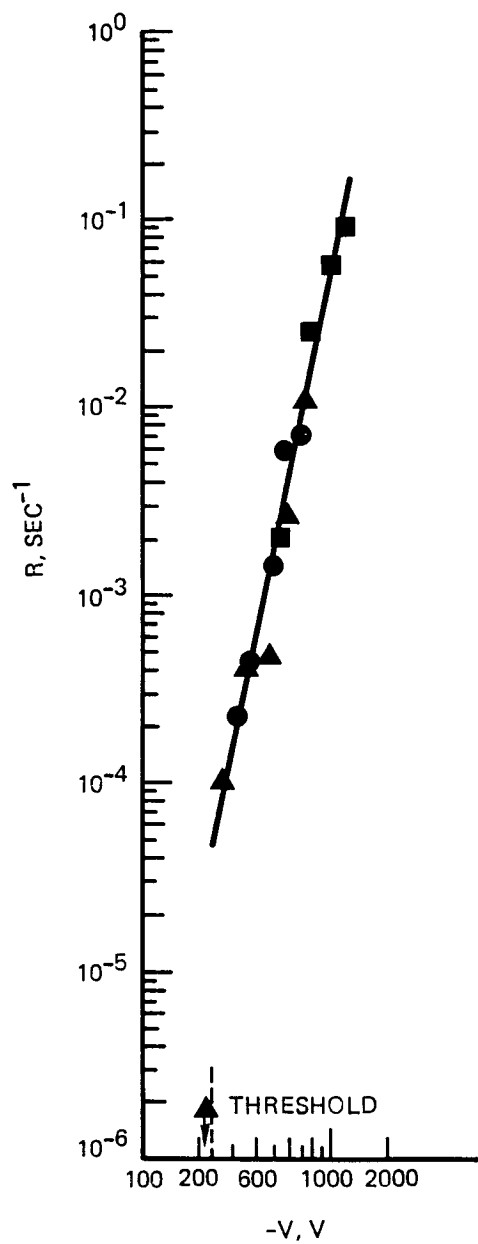


Fig. 9. Arc Rate Predictions Based on Ground Test Data

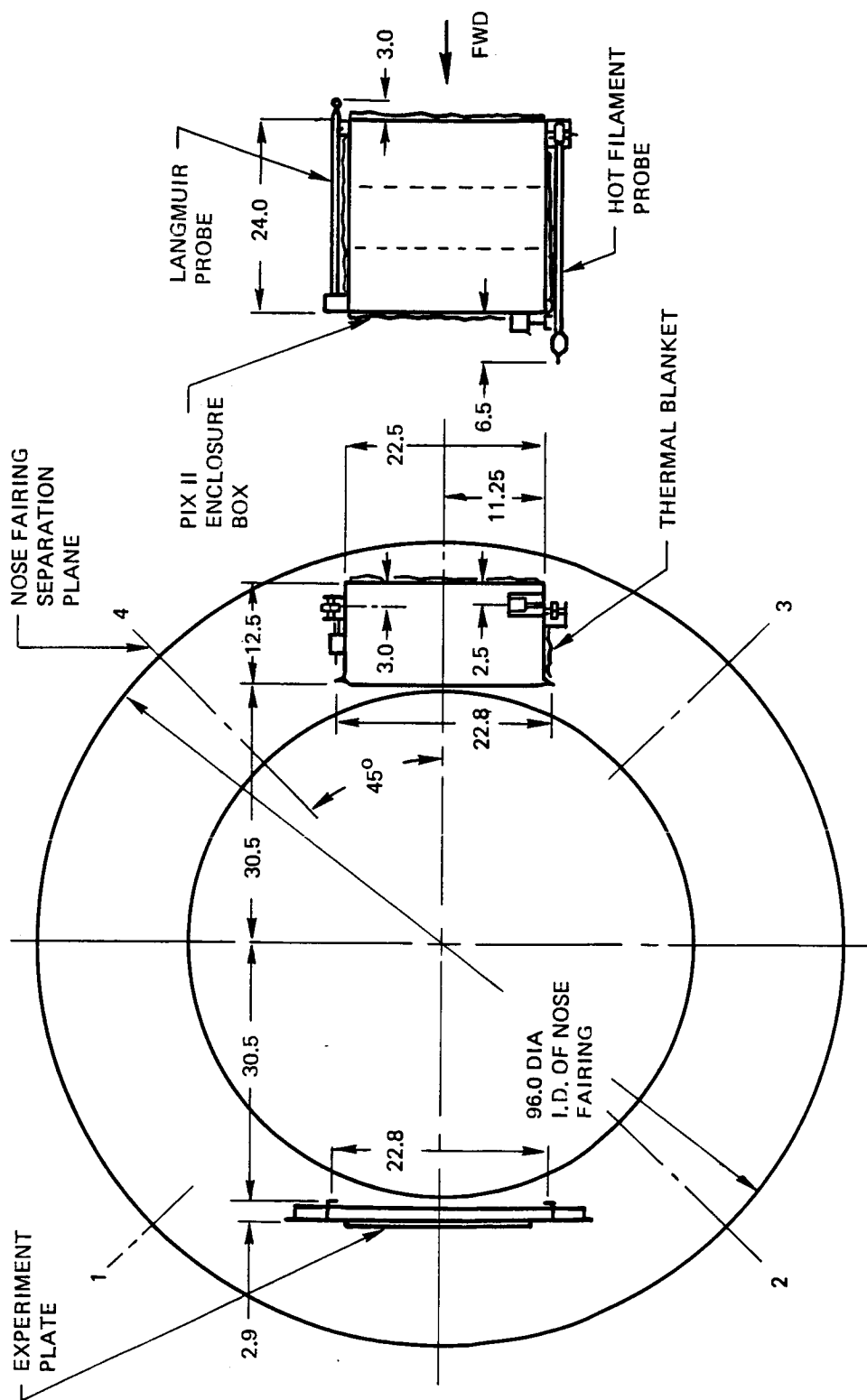


Fig. 10. PIX II/DELTA

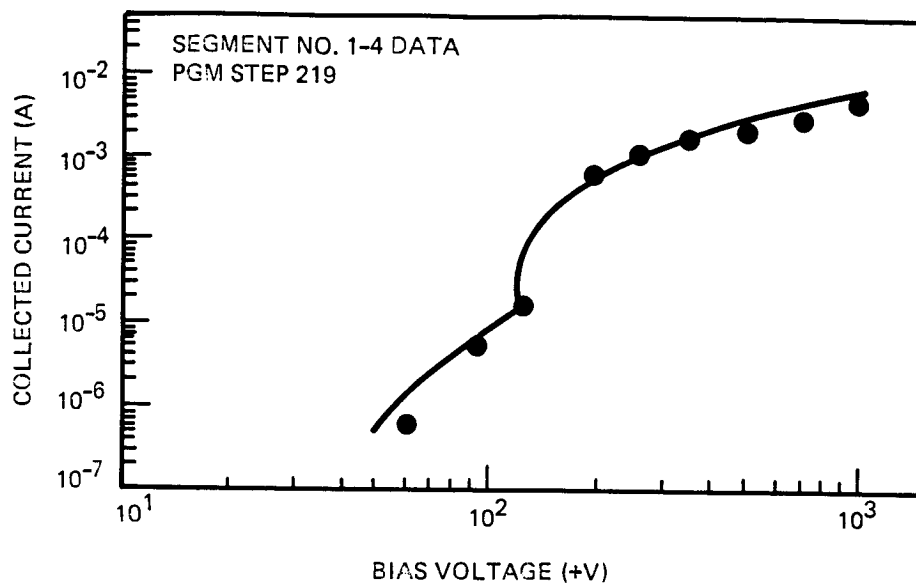


Fig. 11. PIX-2 Data Comparison to Model Predictions
Positive Bias Voltage – Wake and Thermal Modes

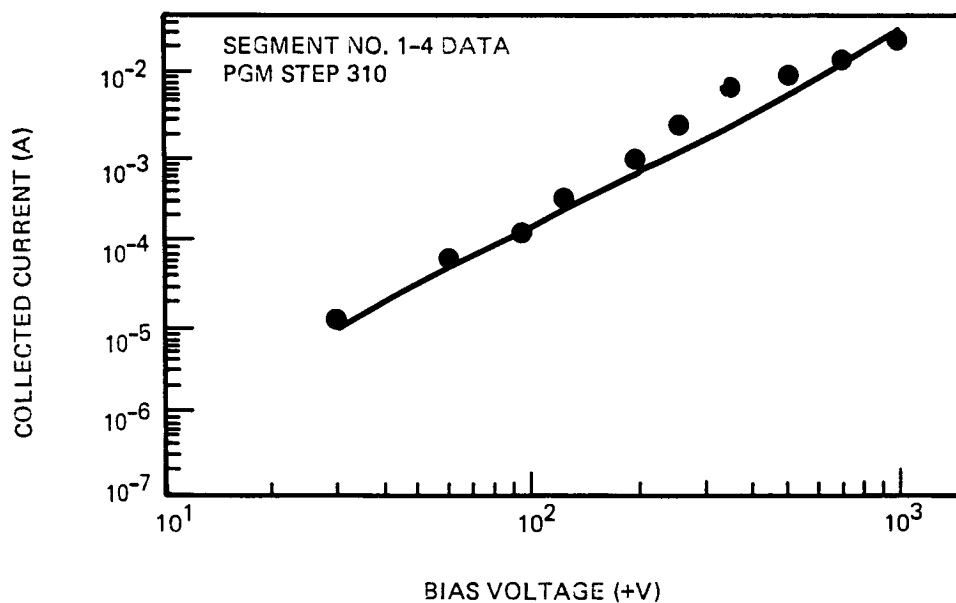


Fig. 12. PIX-2 Data Comparison to Model Predictions
Positive Bias Voltage – RAM Mode

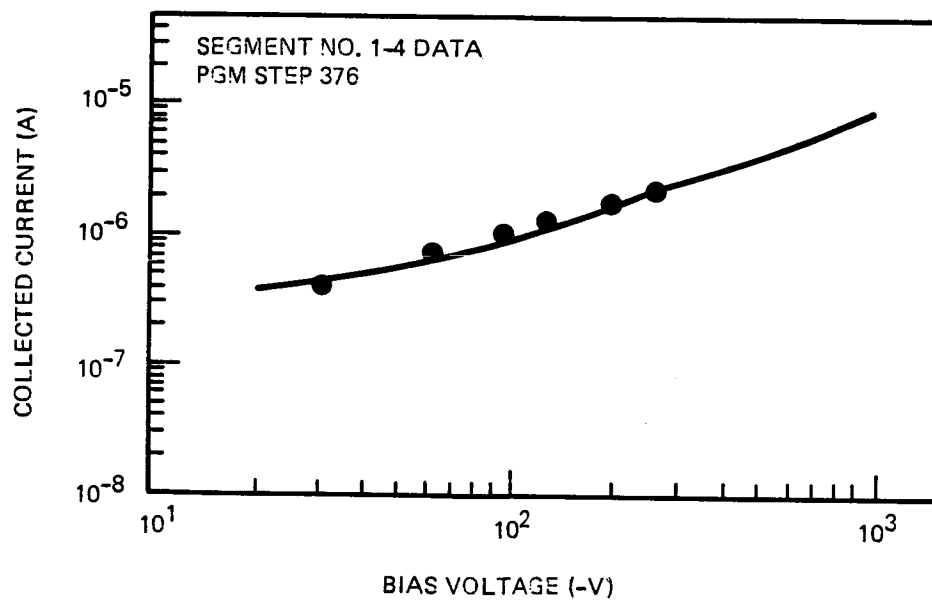
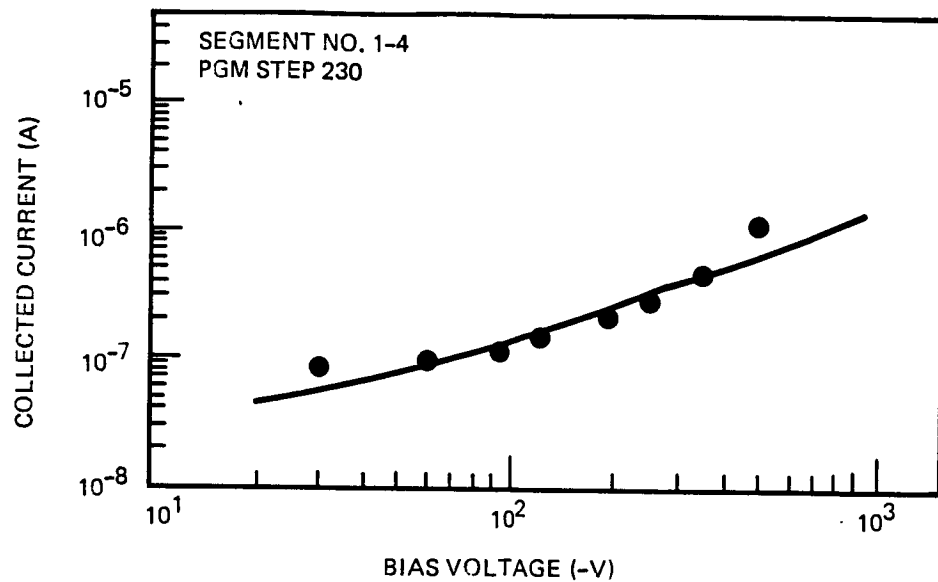


Fig. 13. PIX-2 Data Negative Bias-Ion Collection

4 Segments Biased

A - WAKE

B - THERMAL

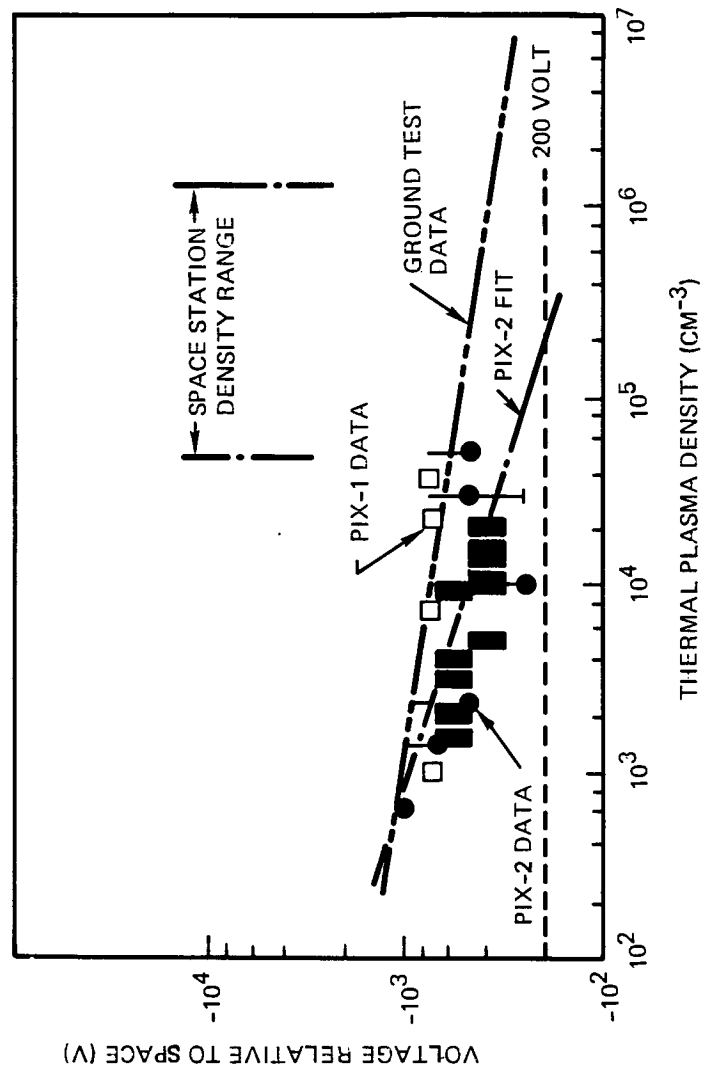


Fig. 14. Shutdown Thresholds

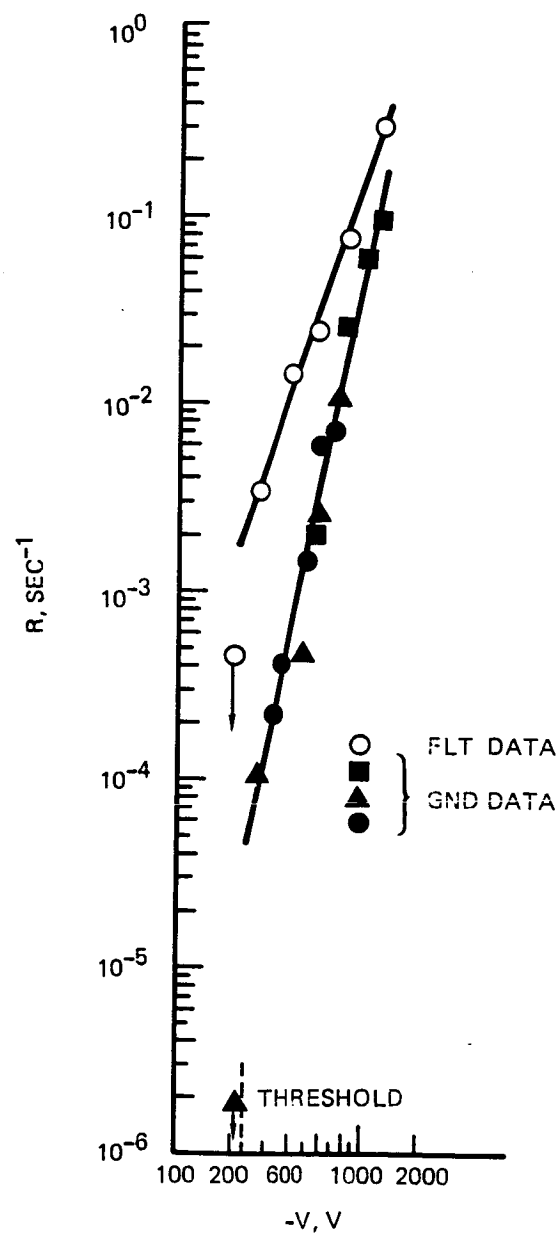


Fig. 15. Arc Rate Comparison Between Ground and Flight Data

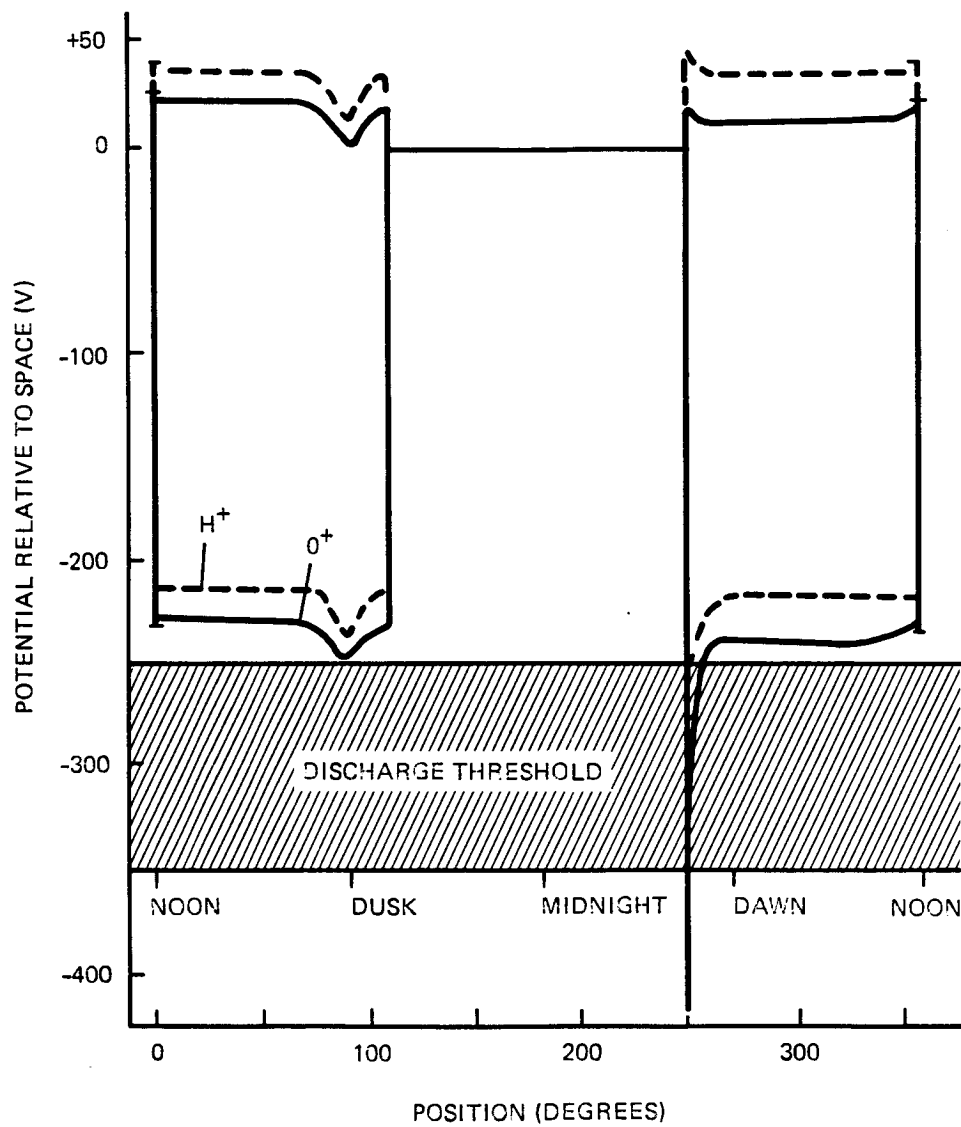


Fig. 16. Floating Potential for 215 kW Array 250 volt Operation — 8 x 8 cm Cells

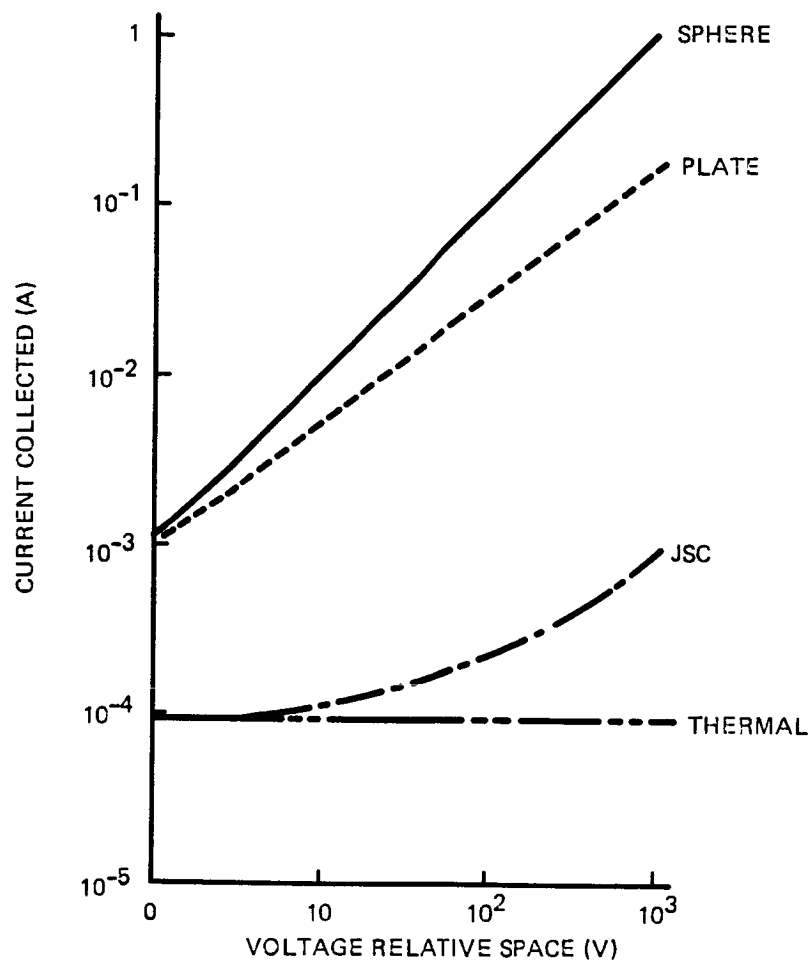


Fig. 17. Flat Plate Plasma Currents (Model Predictions)

10 M^2 Plate — 400 km Plasma

PLASMA-SYSTEMS INTERACTIONS TECHNOLOGY

CAROLYN K PURVIS

NASA/LEWIS RESEARCH CENTER

CLEVELAND, OHIO

SEPTEMBER 24, 1986

PRECEDING PAGE BLANK NOT FILMED

THE TERRESTRIAL SPACE ENVIRONMENT

-EFFECTS ON SPACE SYSTEMS-

ENVIRONMENTAL FACTOR

GRAVITY

SUNLIGHT & ALBEDO

METEORIDS & DEBRIS

NEUTRAL ATMOSPHERE

FIELDS

PLASMAS

FAST CHARGED PARTICLES

SYSTEM GENERATED

ENHANCED

EFFECTS

ACCELERATION, TORQUES

HEATING, POWER, DRAG, TORQUES, PHOTOEMISSION.

MATERIAL DAMAGE, SENSOR NOISE

MECHANICAL DAMAGE, ENHANCED PLASMA INTERACTIONS

DRAG, TORQUE, MATERIAL DEGRADATION, HEATING

TORQUES, DRAG, SURFACE CHARGES, POTENTIALS

CHARGING, INDUCED ARCING, POWER LOSSES.

POTENTIALS, ENHANCED CONTAMINATION, CHANGE OF

E-M REFRACTIVE INDEX, PLASMA WAVES & TURBULENCE

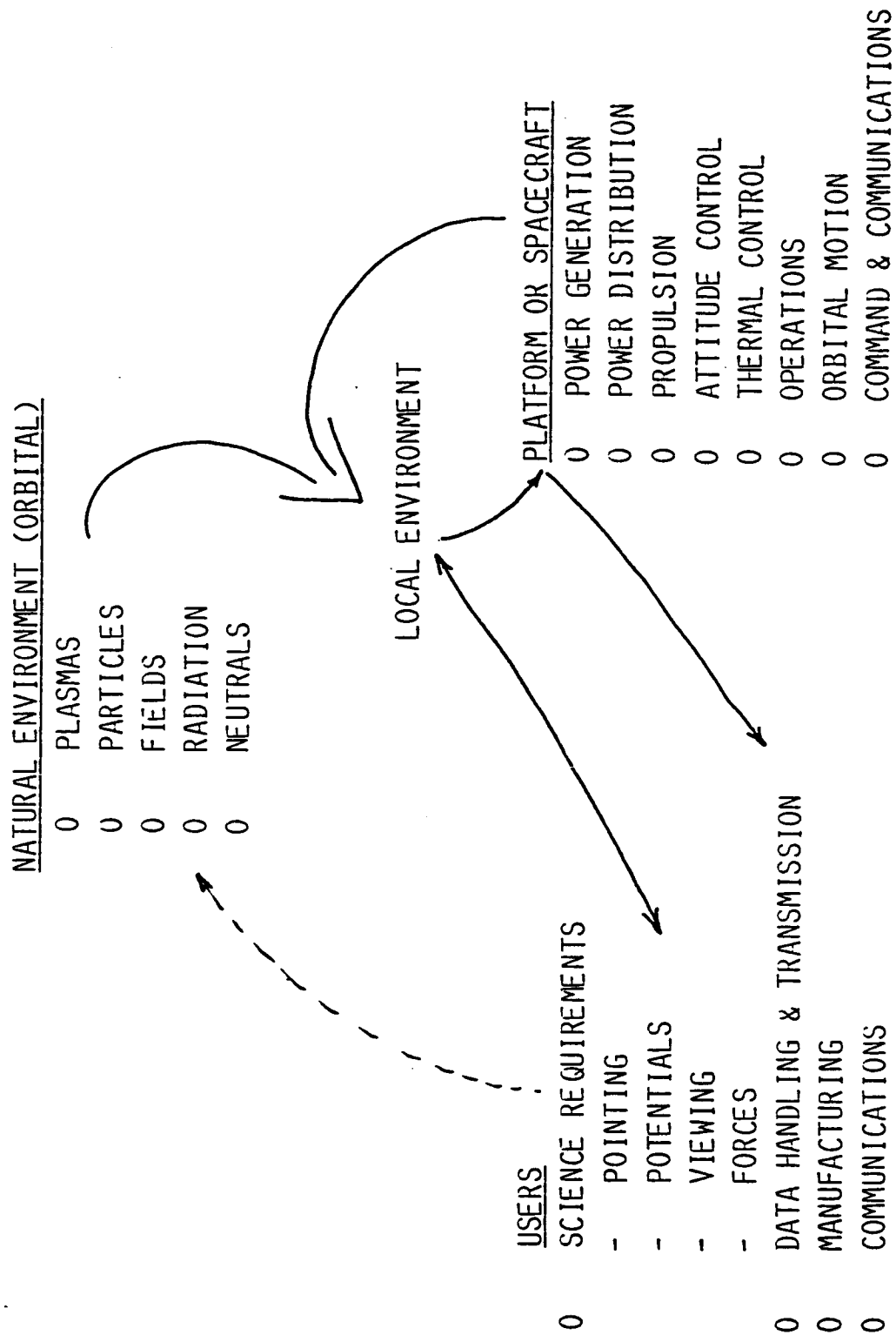
RADIATION DAMAGE, ARCING, SINGLE EVENT UPSETS,

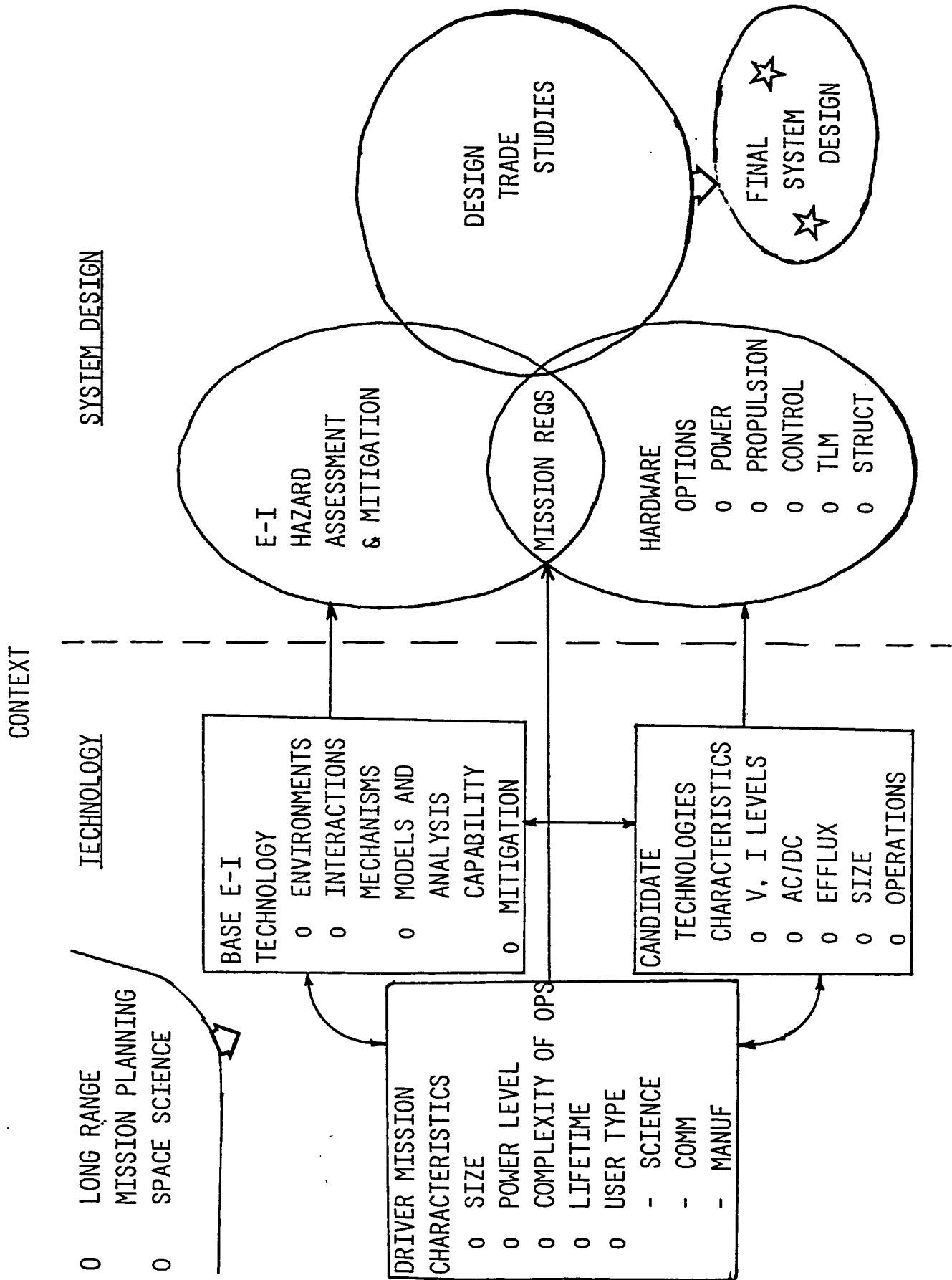
NOISE, HAZARD TO MAN

SYSTEM DEPENDENT: NEUTRALS, PLASMAS, FIELDS
VIBRATION, TORQUES, RADIATION, PARTICULATES

EMP & RELATED

ENVIRONMENTAL INTERACTIONS CONCEPT





INTERACTIONS

- 0 SURFACE AND BULK CHARGING
 - ENVIRONMENT DRIVEN
 - SYSTEM DRIVEN
 - STATIC & DYNAMIC
- 0 PLASMA AND SHEATH EFFECTS
 - DC
 - AC: EM & PLASMA COUPLING
 - MULTICOMPONENT PLASMAS
 - DYNAMIC EFFECTS, INCLUDING TURBULENCE, INSTABILITIES, ES & EM NOISE
- 0 RAM/WAKE EFFECTS
 - LARGE BODIES
 - MULTIPLE SPECIES
- 0 EMI/RFI ASSOCIATED WITH
 - ARCING
 - AC SYSTEMS
 - DYNAMIC PLASMA EFFECTS
 - WAKE EFFECTS
- 0 SYNERGISM WITH OTHER ENVIRONMENTAL FACTORS
 - METEOROID DAMAGE
 - RADIATION
 - ETC.

HISTORY: PLASMA-SYSTEM INTERACTIONS TECHNOLOGY

MID 1960'S TO 1974

HIGH VOLTAGE ARRAYS FOR DIRECT DRIVE OF COMMUNICATIONS EQUIPMENT

- 0 LABORATORY STUDIES OF PHENOMENOLOGY: LERC, HUGHES, BOEING, TRW
 - CURRENT COLLECTION, PINHOLES
- 0 SPHINX FLIGHT EXPERIMENT (1974)
 - LOST DUE TO LAUNCH VEHICLE MALFUNCTION

1975-1981

SPACECRAFT CHARGING IN GEO: NASA/AF JOINT PROGRAM

- 0 ELECTRON BEAM TESTING
- 0 NASCAP
- 0 DESIGN G/L

- LOW LEVEL PLASMA-HV ARRAY EFFORT
- 0 LAB TESTING AND ANALYSIS
 - 0 PIX-I (1978)
 - 0 SEP SUPPORT

1981 TO PRESENT

SPACECRAFT-ENVIRONMENTAL INTERACTIONS: NASA/AF PROGRAM

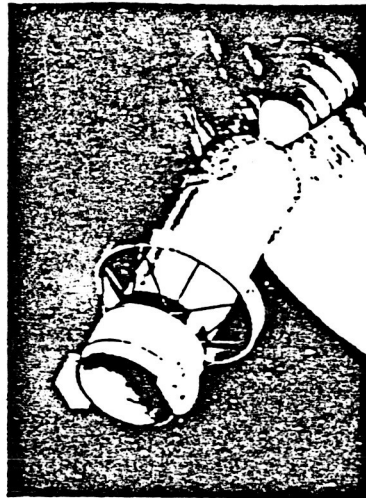
- 0 AF: POLAR ORBIT CHARGING
- 0 NASA:
 - HIGHER VOLTAGE SYSTEM EFFECTS
 - EARLY FOCUS ON ARRAYS IN LEO
 - LABORATORY TESTING
 - THEORY
 - NASCAP/LEO DEVELOPMENT
 - PIX-II (1983)
- 0 OAST PROGRAM REFOCUSSED IN SS ERA

Lewis Research Center,

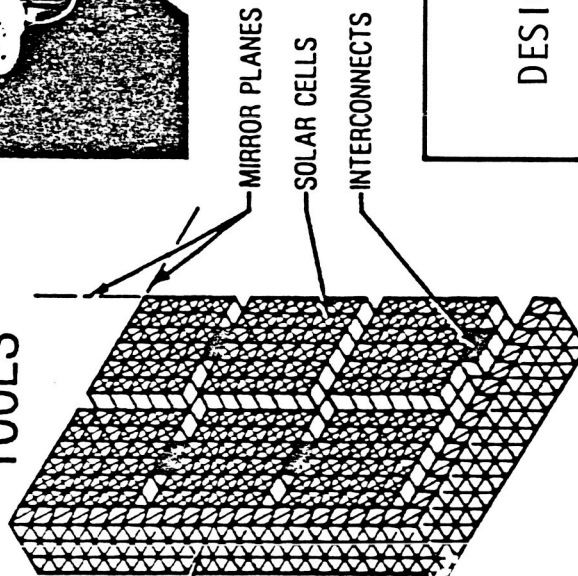
NASA/AF ENVIRONMENTAL INTERACTIONS INVESTIGATION

ENVIRONMENTAL INTERACTIONS

FLIGHT EXPTS



ANALYTICAL TOOLS



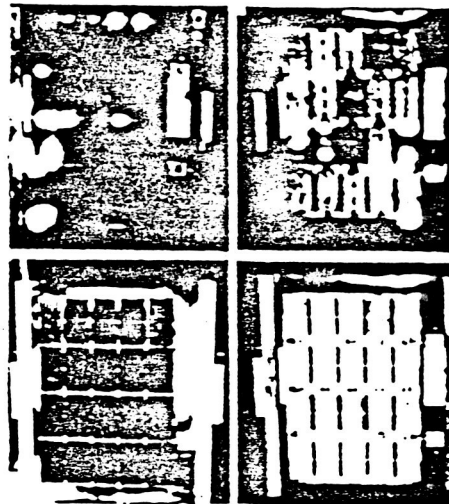
MIRROR PLANES

SOLAR CELLS

INTERCONNECTS

DIELECTRIC BORDER

GROUND BASED SIMULATION



DESIGN CRITERIA
AND TEST STANDARD
DOCUMENTS

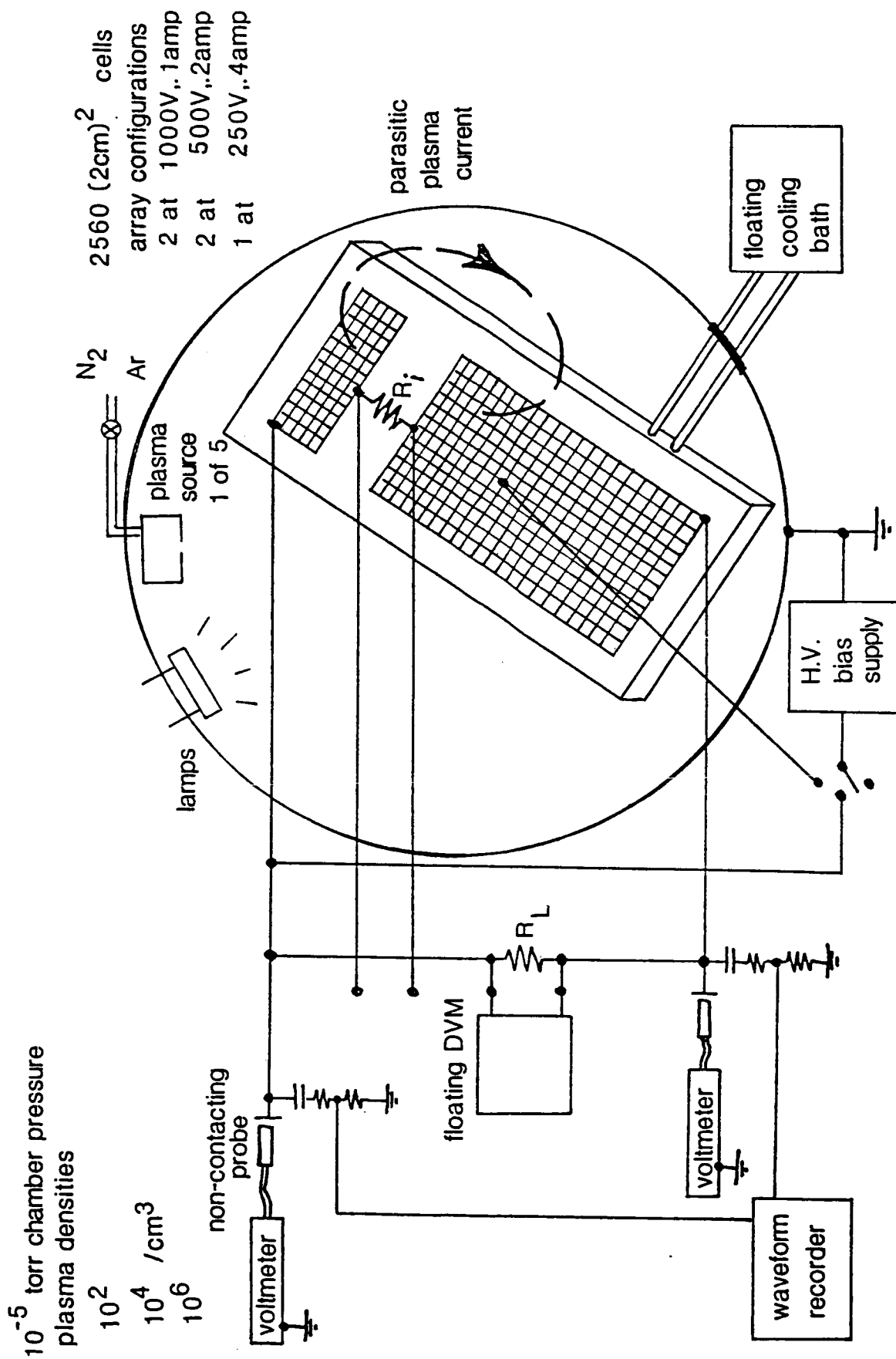
ORIGINAL PAGE IS
OF POOR QUALITY

3-D Model Capabilities Comparison

	<u>NASCAP/GEO</u>	<u>NASCAP/LEO</u>	<u>POLAR</u>
STATUS	Completed	Under Development	Under Development
PURPOSE	Charging in GEO	LEO Orbit Effects	Polar Orbit Effects
ENVIRONMENT	Substorm Plasmas Electron Beams	Ionospheric Plasma	Ionospheric Plasma Auroral Electron Beams
OBJECT SIZE*	Small	Large	Large
MOTION EFFECTS	No	Simple	Yes
COMPLEX OBJECTS	Yes	No	Yes
APPLIED VOLTAGES	Yes	Yes	No
GRID SUBDIVISION	No	Yes	No

* Compared to plasma Debye length

HIGH VOLTAGE SOLAR ARRAY-PLASMA INTERACTION TEST



ACTIVE HIGH VOLTAGE SOLAR ARRAY TESTS

CONDITIONS:

PLASMA: $\eta_e \sim 7 \times 10^6/\text{cm}^3$ $T_e \sim .8 \text{ eV}$
 $\phi_p \sim 4.3 \text{ V}$ $T_i \sim 3.3 \text{ eV}$

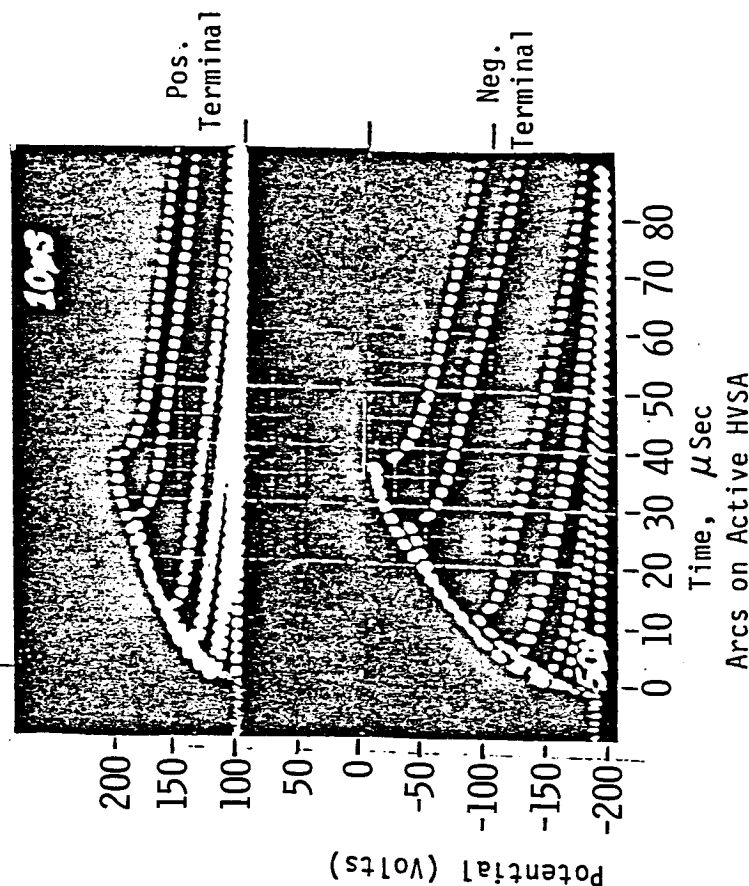
ARRAY: OPEN CIRCUIT

$V_{\text{term}} \sim 300 \text{ V}$ BEFORE ARCS

$\Delta V_{\text{term}} \sim 80 \text{ V}$ DURING LARGEST ARC

RESULTS

- 0 ARRAY FLOATS MORE POSITIVE THAN SIMPLE MODELS PREDICT
- 0 BORDER POTENTIAL HAS SIGNIFICANT EFFECT ON FLOATING POTENTIALS
- 0 ARCS OBSERVED WITH TERMINAL VOLTAGES AS LOW AS 180 V

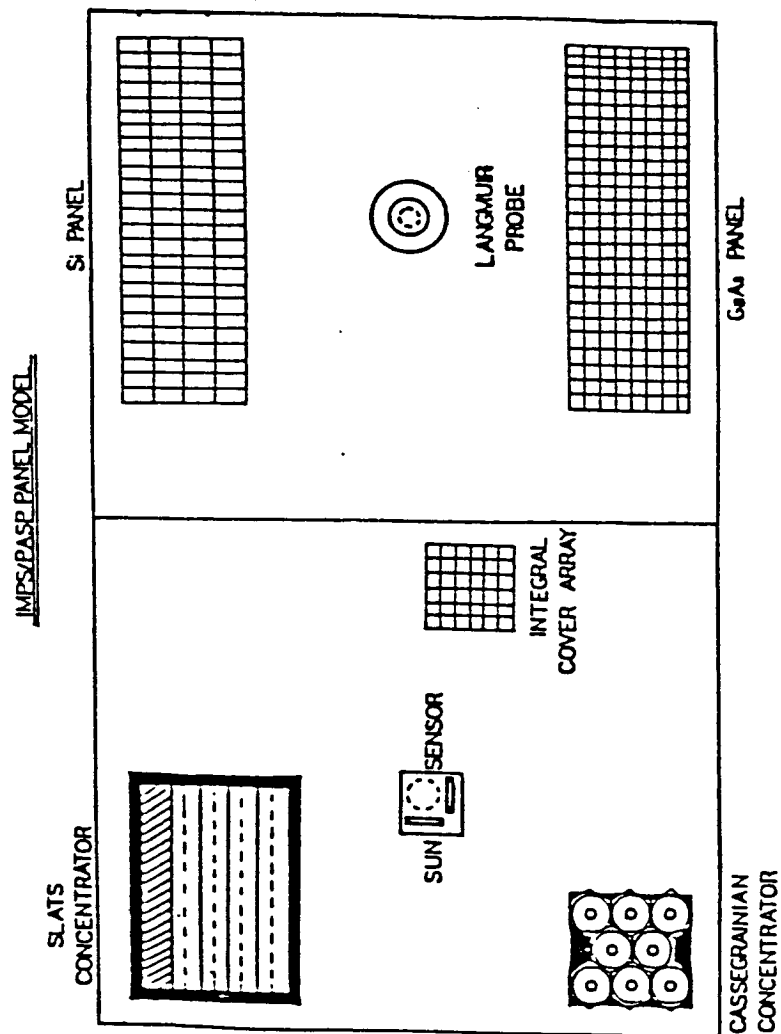


ORIGINAL PAGE IS
OF POOR QUALITY

WHY SPACE EXPERIMENTS?

- GROUND ENVIRONMENT SIMULATION INCOMPLETE
 - PLASMA ENERGY, COMPOSITION, FLOW
 - ORBITAL \vec{B}
 - NEUTRAL COMPOSITION, ENERGY, FLOW
 - RAM/WAKE
 - BOUNDARY CONDITIONS
- LARGE SYSTEM EFFECTS ON ENVIRONMENT NOT WELL KNOWN
- REQUIRE "SPACE TRUTH"
 - "CALIBRATE" GROUND SIMULATION
 - OBTAIN DATA UNDER CONDITIONS THAT CANNOT BE SIMULATED
 - VALIDATE MODELS

PHOTOVOLTAIC ARRAY SPACE POWER (PASP) EXPERIMENT



EXISTING DATA

LABORATORY

- 0 CURRENT COLLECTION BY SHORTED, BIASED CELL STRINGS
 - SMALL AREA SEGMENTS
 - TO ± 1000 VOLTS TYPICALLY
 - PLASMA DENSITIES 10^2 TO 10^6
 - MOST DATA ON 2 X 2 CM CELLS, SOME ON 2 X 4 AND 5.9 X 5.9
- 0 ARCING ON SHORTED, BIASED CELL STRINGS
 - CONDITIONS AS ABOVE

SPACE

- 0 PIX-I (1978)
 - 100 CM² OF 2 X 2 CELLS, SHORTED, ± 1000 VOLTS BIAS
 - 900 KM, POLAR ORBIT
 - 1 HOUR OF DATA RETURNED
- 0 PIX-II
 - FOUR SEGMENTS OF 2 X 2 CM CELLS, 500 CM² EACH, ± 1000 VOLTS BIAS, STRINGS SHORTED
 - 900 KM POLAR ORBIT
 - FULL ORBIT COVERAGE, 16 HOURS OF DATA RETURNED

OTHER DATA USEFUL FOR PLASMA EFFECTS STUDIES

SPACE: "SCIENCE" DATA-PLASMAS, PARTICLES & FIELDS

0 STS

- LARGE, MANNED SYSTEM EFFECTS

- RESPONSE TO VARIOUS ACTIVE EMISSIONS

0 FREE FLYERS

- VEHICLE & SURFACE POTENTIALS

- PLASMA & PARTICLE EMISSION EFFECTS

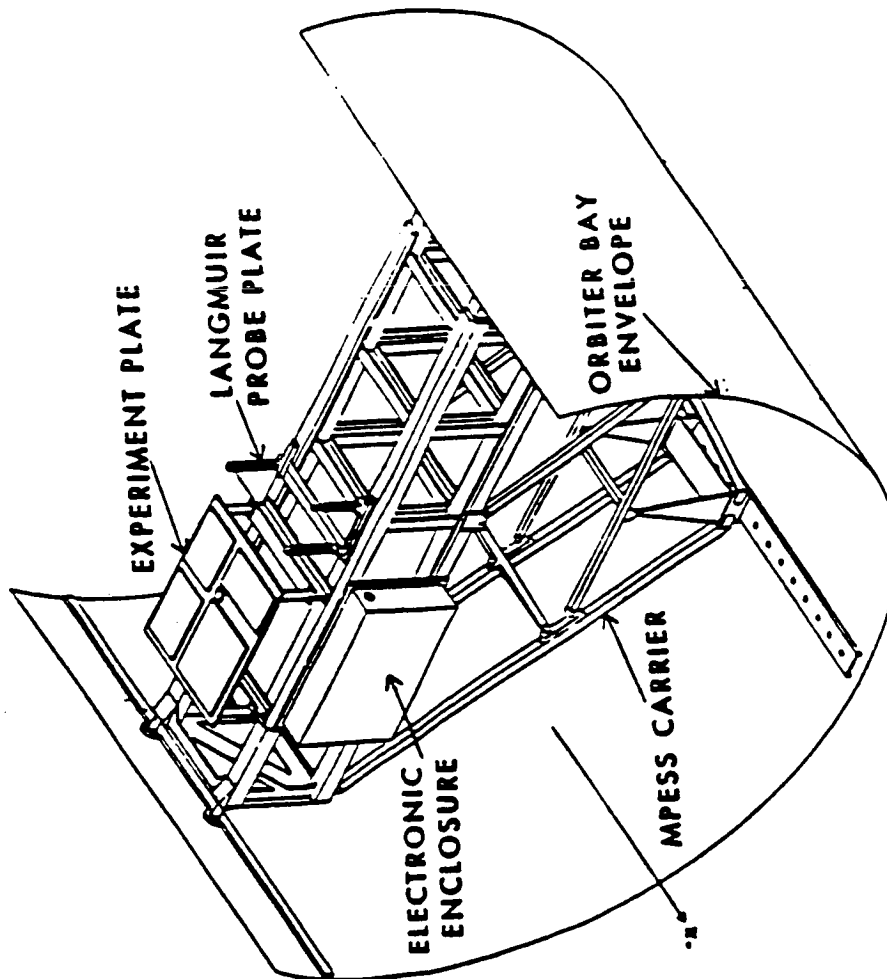
GROUND

0 PLASMA TESTING OF "PIN HOLE" SAMPLES

0 WAKE STUDIES

VOLT-A CONFIGURATION

- EXPERIMENT PLATE (125 LBS)
 - 4 MODULE PLATES (S1 CELLS)
 - 5.9 X 5.9-cm (3)
 - PIX 11 2 X 2-cm
 - SUN SENSOR
- LANGMUIR PROBE PLATE (25 LBS)
 - LANGMUIR PROBES
 - CYLINDRICAL
 - SPHERICAL
- ELECTRONIC ENCLOSURE (150 LBS)
 - POWER SUPPLY/CONDITIONING
 - SEQUENCER
 - VACUUM GAUGE
 - HEATERS
 - TAPE RECORDER



PLASMA INTERACTIONS TECHNOLOGY

RECOMMENDED PROGRAM

OBJECTIVE: DEVELOP MODELING AND ANALYSIS CAPABILITY TO ENABLE CORRECT INCORPORATION OF P-I EFFECTS ASSESSMENT INTO INNOVATIVE TECHNOLOGIES AND SYSTEM/SUBSYSTEM/INSTRUMENTATION DESIGN AT ALL PHASES.

APPROACH:

- 0 DEFINE THE LOCAL ENVIRONMENT
- 0 UNDERSTAND THE PHYSICAL PHENOMENA
 - DETERMINE PHENOMENOLOGY OF INTERACTIONS
 - IDENTIFY DOMINANT INTERACTIONS MECHANISMS
 - DEVELOP AND VALIDATE MODELS
- 0 DEVELOP ANALYTICAL TOOLS AND DATA BASES

REQUIRES:

- 0 MODELING, GROUND TESTING AND FLIGHT EXPERIMENTS
- 0 CLOSE COOPERATION WITH
 - PLASMA SCIENCE
 - S/C DESIGNERS
 - RELEVANT DISCIPLINE TECHNOLOGISTS

PLASMA INTERACTIONS TECHNOLOGY

PAYOFF

SPACECRAFT

- 0 ENHANCED OPERATIONAL RELIABILITY PREDICTABILITY
- 0 ENHANCED SCIENCE RETURN

LARGE SYSTEMS

- 0 ENABLES VERY HIGH POWER SPACE SYSTEMS (INCLUDING LUNAR, MARS BASES)
- 0 ENABLES RELIABLE AUTOMATED SYSTEMS
- 0 PREDICTABLE OPERATION
- 0 ENHANCED LARGE PLATFORM BASED SCIENCE
- 0 GUIDE DEVELOPING DISCIPLINE TECHNOLOGIES

CONCLUSIONS

- 0 P-I IS AN ESSENTIAL BASE TECHNOLOGY
 - COMPLEMENTARY TO SPACE SCIENCE AND DISCIPLINE TECHNOLOGIES
 - REQUIRED INPUT FOR DESIGN TRADE STUDIES
- 0 IMPORTANCE/IMPACT INCREASES WITH
 - SYSTEM POWER, SIZE AND LIFETIME
 - AUTOMATION LEVEL
 - COMPLEXITY OF OPERATIONS
 - SENSITIVITY OF INSTRUMENTATION
- 0 A STRONG P-I TECHNOLOGY PROGRAM REQUIRED
 - MODELING
 - GROUND TEST
 - FLIGHT EXPERIMENTS
 - CLOSE COORDINATION WITH RELATED SCIENCE & TECHNOLOGY
 - COOPERATION WITH SYSTEM DESIGNERS